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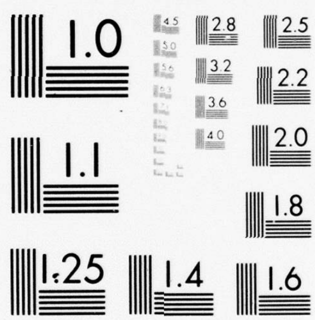

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FLIGHT SIMULATOR MAINTENANCE TRAINING: POTENTIAL USE OF STATE-OF-THE-ART SIMULATION TECHNIQUES

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NOTICE

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

MARTY R. ROCKWAY, Technical Director
Technical Training Division

RONALD W. TERRY, Colonel, USAF
Commander

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A study was undertaken to evaluate the potential application of state-of-the-art simulation technology to the area of maintenance training. The vehicle of the study was the 341XX career field, which is concerned with the maintenance of digital flight simulators. An analysis was performed on the types of maintenance tasks, especially troubleshooting tasks, performed by technicians in the field. An analysis was also done on the technical school training for this career field. Two technical school courses were the focus of study: Digital Flight Simulator Specialty (341X4) and Digital Navigation/Tactics Training Devices Specialty (341X6). The results of the task analysis and training analysis were used in a study to determine the types of simulation training approaches that would be most suitable for supporting the assessed training needs. Three training concepts were developed to

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support the types of maintenance skills and knowledges required in the 341XX career field. Air Force personnel then selected two of these training concepts for translation into prime item development specifications.

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SUMMARY

Factors such as sophistication, variety, and increased utilization of flight simulators and navigation/tactics trainers are putting great demands on training qualified maintenance personnel. Increased flight simulator utilization is due mainly to the worldwide fuel shortage, coupled with the aircrew training effectiveness realized from the use of these training devices. Because of increased utilization rates, the criticality of downtime is an ever increasing problem. Therefore, on-site maintenance training on the actual flight simulator equipment is becoming limited. The availability of simulators dedicated to formal technical school maintenance training is also becoming virtually non-existent because of field requirements for the prime mission of the devices, which is to train pilots and navigators. Even if actual flight simulators were available for training, factors such as reliability, safety, malfunction capabilities, noise, and instructional control argue against their use. Further, because of the safety issue, both for personnel and the equipment, "hands-on" experience with actual system equipment is severely limited.

Purpose of Study

The purpose of this study was to analyze the Digital Flight Simulator Specialty (341X4) and the Digital Navigation/Tactics Training Devices Specialty (341X6) to determine the potential for applying maintenance simulation in support of both on-site and formal maintenance training within the 341XX career field.

Objectives of Study

The objectives of this effort were:

1. Conduct a task analysis of the 341X4 and 341X6 specialties to identify maintenance skills needed for the apprentice through the technician level.

2. Analyze existing training.

3. Report potential cost-effective applications of simulation technology to support the necessary maintenance knowledges and skills.

4. Provide two sets of functional specifications for selected maintenance simulators.

Study Results

The task analysis resulted in the description of 250 discrete maintenance tasks, and these tasks were described in terms of a series of cues and actions taken to isolate the cause of system malfunctions. This analysis indicated that malfunctions were most frequently related to the following digital simulator subsystems: simulated visuals (model boards and indicators), radar simulation, digital computer system, and instructor/operator stations.

The training analysis led to the categorization of course content in terms of six training categories. The two technical training courses were found to emphasize knowledge of simulator-related components and, to a lesser extent, basic support skills, that is, troubleshooting and repair. The two technical training courses were also analyzed with respect to their Specialty Training Standards (STSs). The course content for the two specialties was found to emphasize digital computers, aircrew training devices, circuit analysis and alignment, maintenance of aircrew training devices, operation and use of aircrew training devices, circuits and components, and tools and test equipment.

An effort was subsequently undertaken to define the type of maintenance training devices incorporating simulation needed for supporting the maintenance skills identified as a result of the task and training analyses. Descriptions of several candidate training devices incorporating simulation technology were discussed in coordinating sessions with Air Force personnel. Two trainer concepts were selected for further development: (a) a Scaled-Down Simulator; and (b) a Troubleshooting Trainer. The Scaled-Down Simulator is a device to support the learning of basic support skills and concepts during technical school training. The Troubleshooting Trainer is a device to teach the conceptual aspects of system troubleshooting for specific simulator systems. These two simulator concepts were then developed into prime item development specifications.

Conclusions and Recommendations

This study concluded that simulation training is suitable for the area of flight simulator maintenance training. In order to achieve the greatest benefit from introducing simulation training devices into training in the 341XX career field, emphases need to be placed on current technical school and on-the-job training to maximize the learning of the identified knowledges and skills. Technical school training should stress the basic knowledges and support skills, as well as information on hardware elements and configuration of flight simulator systems. Field maintenance training, on the other hand, should stress the specific knowledge and troubleshooting skills related to the actual digital flight simulator system being maintained.

Recommendations were made to include a greater emphasis on the development of system troubleshooting skills during technical training. Suggestions were also made for future research efforts in simulation technology as applied to the area of maintenance training.

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INTRODUCTION

Background of Study

Digital flight simulators are now used extensively by the Air Force to train pilots and navigators because they have proven to be both training effective and cost-effective. By incorporating sophisticated digital computers, linkage hardware, and peripherals, flight simulators can reproduce the characteristics of specific aircraft with a high degree of fidelity. For these reasons, the number and use of flight and navigation/tactics simulators are steadily increasing, and as a result, the pressure on maintenance personnel to keep the simulators in a constant state of operational readiness is likewise increasing. The time may come when downtime on a flight simulator will be as costly as aircraft downtime in terms of both skilled readiness of aircrews and training capabilities. Simulator maintenance, therefore, is becoming a topic of major concern for the Air Force.

Simulator maintenance training is provided for the Airman Training Devices Career Field (341XX). Technical training is provided for the Digital Flight Simulator Specialty (341X4) and the Digital Navigational Tactics Training Devices Specialty (341X6) at Chanute Air Force Base. There are three skill levels within each specialty: apprentice, specialist, and technician--the 3, 5, and 7 levels, respectively. The training courses are the 3ABR34134 Basic Digital Flight Simulator Course and the 3ABR34136 Basic Digital Navigation/Tactics Training Devices Course. Airmen in both fields receive the mandatory Basic Electronics Training (ET) course as a prerequisite.

A problem associated with the current technical training offered in each of these courses is the lack of digital flight simulators and associated training devices available for use. Because of this lack of training equipment a large part of each course is spent in classroom instruction in fundamentals, with little opportunity for "hands-on" maintenance experience.

Problem Areas Under Investigation

Because of the rapidly increasing need for maintenance personnel in the digital flight simulator field and the requirement to promote and upgrade the level of maintenance training available to these personnel both in technical school and in the field, the Air Force Human

Resources Laboratory (AFHRL) is undertaking a program to examine the feasibility of applying the principles and technologies of simulation to the training of these personnel. The IEEE Standard Dictionary of Electrical and Electronics Terms (1977) defines "simulate" as "to represent the functioning of one system by another, for example to represent one computer by another, to represent a physical system by the execution of a computer program, to represent a biological system by a mathematical model." The term "simulation" refers to concepts or processes, while the term "simulator" is used to refer to physical objects or devices which employ simulation.

Military maintenance training programs have often used actual equipment under the assumption that the more realistic the hardware, the better the transfer of training. With respect to digital flight simulators, however, the cost of the actual system equipment is prohibitive when considered exclusively for maintenance training applications. Potential safety hazards to trainees are another factor weighing heavily against using system equipment for training, as is damage to the system itself, which could occur when relatively inexperienced technicians work with such complicated and fragile hardware. Further, actual system equipment is seldom designed to support additional training functions. That is, flight simulators are designed to train pilots, not to train maintenance personnel. It is likewise not feasible to introduce realistic troubleshooting problems on real equipment for training purposes because they would have to be introduced in unconventional ways (e.g., taping relay contacts) and consequently would not represent faults actually encountered on the job.

Simulators as Instructional Media. Simulators appear to offer many potential advantages over actual system equipment as instructional media. Compared with actual system equipment, simulators can be less expensive, much safer, and may be designed specifically for training applications. Why then are simulators not used exclusively for training applications? A partial answer to that question is that simulators must be specially designed for instructional applications. Design effort requires a great deal of analysis and understanding with respect to the skills to be trained, the characteristics of the personnel to be trained, the characteristics required of the instructional device, the psychology of learning, the problem of transfer of training, and the use of the device within the instructional program. Potential advantages of simulators as instructional media are indeed great, but achieving these advantages requires firm theoretical foundations as well as practical experience.

Simulators should not be considered primarily as attempts to represent actual system equipment, but should be considered as attempts to recreate specific man-machine interactions, or behaviors. Simulators should not be designed to replicate all possible job-related behaviors, but should focus on critical, important, or unique skills. Procedures for identifying job-related skills are generally

called "task analysis," and procedures for performing this type of analysis have been described by Shriver and Hart (1975) and Cream et al (1978). Task analysis procedures should result in the development of specific objectives to be achieved as a result of training, and methods for measuring or assessing these learned skills.

Simulators must also permit control over the instructional process. Topics included under instructional control may include selection of the topic to be trained, selection of problem difficulty, application of instructional strategies or procedures, control over reinforcement contingencies, providing knowledge of results, and determination of satisfactory from unsatisfactory trainee performance. Instructional control, then, requires a means for measuring the development of trainee skills and for assessing the achievement of the specified training objectives. Permanent records should be made of trainee behavior so that training effectiveness may be determined. Assessment of training should also be carried out once the trainees have been placed on their job to determine the degree of training transfer, and to make adjustments to the skills to be trained.

Problems of Fidelity. The basic concept behind the use of simulation is the representation of one system by another. Simulation is usually something less than total duplication, so that it is necessary to find a way of expressing shades or degrees of representation. The concept normally employed is that of "fidelity of simulation." Fidelity of simulation refers to the degree of correspondence between the device and the equipment or system it represents. High fidelity simulation means that there is close correspondence, and low fidelity means that there is considerable disparity between the two.

Fidelity of simulation may be addressed with respect to many dimensions. That is, fidelity of simulation may address such characteristics as physical appearance, functional operation, and the outcome of training. Fidelity of simulation may be considered as a complex dimension whereby a single device may have high fidelity on one dimension, medium fidelity on another dimension, and low fidelity on still another dimension.

One problem lies in the fact that there are many different concepts of fidelity described in the literature. Robert B. Miller (1954) has described the concept of engineering fidelity: that is, a simulator can be evaluated in terms of the degree to which it replicates the physical, functional, or environmental characteristics of the primary system. Gagne (1962) has introduced the concept of psychological fidelity. Psychological fidelity refers to the trainee's perception of realism. A training device may not use duplicate hardware, but may "appear" realistic to the trainee with respect to his interaction with the system. Psychological fidelity is assessed by the degree to which skills learned with the simulator are shown to have a

high degree of transfer to the job. These two concepts of simulation fidelity are basically different: one focuses on the primary system hardware, and the other focuses on the results of trainee learning as measured by transfer of training studies. A third concept of simulation fidelity is that of behavioral fidelity. Behavioral fidelity, a term introduced by the authors, focuses upon the replication of man-machine interactions (behaviors) determined as a result of task analytic procedures. Behaviors are often expressed in psychological terms, that is, stimulus, response, feedback, and related conditions. Behavioral fidelity can be assessed in terms of how well a training device permits the exercise of specific job tasks or related man-machine behaviors. Fidelity of simulation, then, may be considered separately for each behavior to be trained, and the degree of fidelity should be selected to support both the learning and transfer of training of specific behaviors.

Another problem area concerns fidelity and task grouping. A single training device may be required to support the learning of many apparently unrelated job tasks. The task of designing simulators and determining appropriate levels of simulation fidelity would be much easier if these tasks could be grouped, or categorized, according to some training-related scheme. Such a taxonomic scheme could sort tasks into discrete categories, each category encompassing a relatively unique requirement for simulation fidelity, relatively unique training approaches which would be effective, and relatively unique considerations to promote transfer of training. Many such schemes have been developed for categorizing tasks for the purpose of training, but none of these schemes has proven to be entirely satisfactory. One often made distinction is between cognitive tasks and noncognitive (that is, involving motor skills) tasks. Gagne (1965) has described four such categories of tasks: (a) discrimination, (b) identification, (c) sequence learning, and (d) problem solving. Additional effort is required to develop suitable schemes for categorizing job and training tasks for successful application of simulation technology to military maintenance training.

Training media must do more than permit the replication of job-related behaviors, they must also permit control over the instructional process. That is, the simulator must perform a dual training role, that of supporting specific behavioral interactions and that of actively contributing to the instructional process. It seems apparent that the more instructional control employed, the less faithful the simulator will be with respect to replicating the existing job task. Training procedures which lower fidelity to increase support of the learning process include (a) feedback and reinforcement to trainees, (b) measurement, testing, performance recording, (c) compression or expansion of time frames, (d) altered sequences of events, such as starts, stops, and problem freeze, and (e) variations in problem difficulty.

Performance measurement is another requirement for instructional media. Measurement capabilities are essential during the training process to provide reinforcement and control over the instructional process. Additionally, records are needed of student success with respect to the achievement of training objectives. Performance records are also needed to assess transfer of training, to adjust and update instructional content, and for administrative purposes.

Fidelity of simulation may be varied considerably by stage of learning to increase training effectiveness. The initial stages of learning are concerned primarily with establishing specific behaviors rather than with the refinement of skills. Part-task trainers may be used most effectively during the early stages of learning. Other techniques may be used which lower simulation fidelity but which increase learning. Examples of these techniques include:

- Graphics which eliminate extraneous detail and employ labels and call-outs.
- Prompts, hints, and explanatory aids.
- Augmented cues, that is, unique presentations of performance feedback.
- Distortions of size relationships, time frame, and physical relationships.
- Variations in problem difficulty.
- Remediation for areas of weakness.
- Applications of learning strategies.

These techniques are normally not fully applicable during the later stages of training, when training progresses from part-task trainers to whole-task trainers. Fidelity of simulation is usually increased during these later stages to increase transfer of training. Ultimately, simulation training should be blended with training on actual system equipment to produce the best possible transition between training and actual job performance.

Fidelty and Transfer of Training. Fidelity of simulation is considered to be a major learning parameter concerned with transfer of training. Since the ultimate objective of training is the transfer of learned skills to the job, a sound rationale for specifying simulation fidelity is of utmost importance. Many current approaches to the topic of simulation fidelity were developed with respect to the training of coordinated psychomotor skills, such as those involved in aircraft maneuvering, and are insufficient for the development of mental concepts, problem solving ability, and strategy development.

Different types of behaviors, such as motor skills, discriminations, problem solving, and strategy utilization, may have substantially different requirements for simulation fidelity to promote efficient learning and maximize transfer of training.

One approach to the specification of simulation fidelity is to assume that the higher the fidelity, the better the learning, and hence the greater the transfer of training. This notion is depicted in Figure 1 as adapted from Kinkade and Wheaton (1972). The model in Figure 1 suggests that a single level of fidelity could be chosen for a training device. On the other hand, the present authors suggest that separate levels of fidelity be considered for each of many separate behaviors, and that higher levels of fidelity may be appropriate for some behaviors while reduced fidelity may be appropriate for others. For example, psychomotor skills may require high simulation fidelity for effective learning and transfer of training, problem solving ability may require a wide variety of training experience, and hence low simulation fidelity, for effective learning and to promote maximum transfer of training.

Fidelity and Cost. The fidelity-cost tradeoff model shown in Figure 1 suggests a method for selecting simulation fidelity on the basis of cost. This model suggests that training effectiveness is an ogival curve and that fidelity should be selected near the point of diminishing returns. This rationale for specifying simulation fidelity has been widely quoted. The authors feel, however, that fidelity of simulation should not be considered as a unitary parameter, but should be considered separately for each behavior and for each stage in the learning process. While budget constraints must ultimately enter into decisions, it should be emphasized that fidelity considerations are of primary importance to instructional designers and should be considered first in terms of supporting the learning process, and second in terms of cost.

Conceptual skills appear to be especially suited to low fidelity, low cost trainers. Many studies have found that intellectual skills, concepts, discriminations, and procedures can be trained effectively with low fidelity, low cost devices (Crawford, 1976; Shriver et al, 1961). Complex coordinated psychomotor skills, on the other hand, may require higher fidelty, and more expensive, training devices.

Objectives of the Study

In summary, the objectives of this study were:

- To assess the potential for applying simulation technology to support maintenance training within the 341XX career field by conducting a task analysis and training analysis.

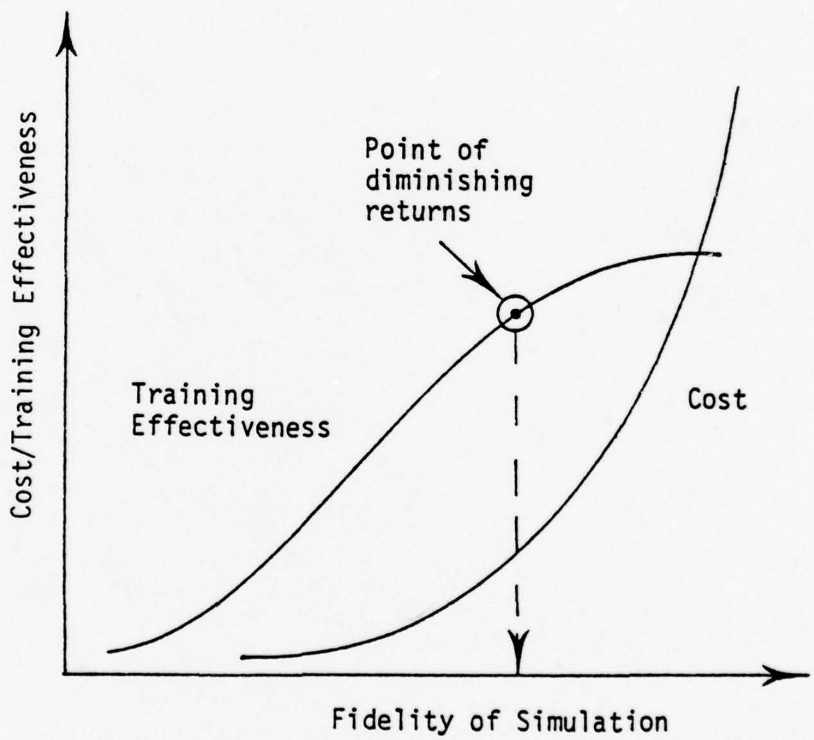


Figure 1. Fidelity-cost tradeoff model adapted from Kinkade and Wheaton (1972) (Adapted from R. B. Miller (1953)).

- To develop simulation training concepts suitable for supporting required skills and knowledges identified during the task analysis and training analysis.

- To prepare functional specifications of two training devices based on these concepts, incorporating simulation technology which could be used to support training in the 341XX career field. These devices were also to serve as a medium for research in the area of maintenance training.

METHODOLOGY

Analytic Framework

Research on this project began with a review of literature relating to flight simulators and associated maintenance tasks, and this literature included Technical Orders (TOs) on operation and maintenance of digital flight and navigation/tactics simulators for the F-4E, F-15, FB-111, E-3A, C-5A, and C-131 aircraft. Concurrently, draft Occupational Survey data (the Occupational Survey was in progress during conduct of the present study) and Specialty Training Standards (STSs) for the 341X4 and 341X6 specialties were also studied.

A series of on-site visits was undertaken to obtain data to be used in subsequent task and training analyses. Data on field maintenance tasks were obtained from (a) structured interviews with personnel working in the career fields, (b) replies to a mailed questionnaire survey of 341X4 and 341X6 personnel working at various field locations, and (c) a study of Maintenance Data Collection Records (MDCRs) obtained from an on-site flight simulator facility.

A training analysis was also performed on the two apprentice-level courses offered at Chanute Air Force Base. These two courses were the 3ABR34134 Basic Digital Flight Simulator Course and the 3ABR34136 Basic Digital Navigation/Tactics Training Device Course.

From these data, various analyses and syntheses were made, and hypotheses and concepts relating to the nature of training aids incorporating simulation were studied. Several candidate training devices were identified as having potential for complementing current training programs offered both in technical schools and on the job. It was recommended that two of these, one designed for technical school use and the other for field use, be developed as prime item development specifications for possible future Air Force procurement and evaluation. Following AFHRL/TT concurrence, two specifications were prepared detailing the functional requirements for two maintenance training simulators.

Task Analysis

A task analysis, oriented toward the interactions between man and equipment, was undertaken to the level of detail necessary only to establish the general characteristics of the tasks to be simulated. This detail, however, was sufficient to support a number of simulator design alternatives. It was felt that a more detailed and elaborate analysis might have tended to narrow the number of viable design alternatives.

Field Survey. To initiate data collection for the task analysis, six sites were visited: Langley AFB and Luke AFB (Tactical Air Command (TAC) bases); Dover AFB and Altus AFB (Military Airlift Command (MAC) bases); Plattsburgh AFB (Strategic Air Command (SAC) base); and the TAC component of Tinker AFB. A structured interview format was prepared and pretested at Chanute AFB on both instructor and maintenance personnel prior to making the site visits.

The interview format was divided into four sections. The first section sought to obtain background information on each interviewee: rank, term of service, field experience, etc. The second section was devoted to obtaining specific maintenance data on particular simulator hardware systems, including initial failure and subsequent chains of cues and responses leading to isolation and correction of the fault. The third section was designed to probe interviewee experience levels, and characteristics of each of the maintenance tasks (for example, difficulty and criticality levels, skill and number of personnel required, and task recurrence). The purpose of the fourth section of the interview format was to obtain data on the effectiveness of training (career development course, on-the-job training (OJT), and technical school training) to support the job tasks. A total of sixty-six (66) personnel were interviewed.

Data obtained from the field visit interviews were transcribed into a task analysis format. The complete task analysis results were delivered in an unpublished Interim Report to AFHRL/TT. A representative task is shown in Figure 2. The task title on each analysis form was determined after analyzing each task in detail, and each title corresponded with a particular task included in the preliminary Occupational Survey task list of the career field developed by the USAF Occupational Measurement Center. The skills/knowledges listed on the form are expressed in terms of paragraph and sub-paragraph number on the respective 341X4 or 341X6 Specialty Training Standards (STS). In this manner, the STS and Occupational Survey data were effectively incorporated into each task analyzed. This coding scheme also formed a basis for the training analysis, described later. For this study, difficulty and criticality indices were based on a scale of 1 to 3, "1" being most critical or difficult, and "3" being least critical or difficult, as reported by interviewees.

The procedures involved in transcribing field data to the task analysis sheets were step-by-step, chronological and logical chains, relating cues and subtasks (cues and responses). The first cue represents the initial observable fault or malfunction in the equipment and was determined either from direct observation or from pilot trainee write-up. The first subtask generally defines the initial troubleshooting strategy adopted to isolate the fault. If the cause is not immediately obvious (and hence readily correctable), tests and measurements may be performed in conjunction with additional strategies to isolate the fault.

Task Title	ISOLATE MALFUNCTION ON INDICATOR SYSTEMS		
System/hardware	F-15 ADI		
Skills/knowledges (STS)	7e; 10; 14e; 19b	Simulation rqmts.	None specified
No. trained personnel required	1	Task difficulty index	3
AFSC/rating required	34154	Task criticality index	1
Test equipment required	(none)	Time required	15 min.

Subtasks	Cues
	1. All lights out on pilot's station, instructor's console.
2. Check circuit breakers (CB) in cabinet.	3. One CB popped.
4. Reset CB.	5. Lights still off.
6. Query pilot on power failure - repeat actions. Pilot on standby on reference indicator.	7. Lights went off again.
8. Check prior maintenance records on AI - verify prior actions.	9. Crimped wires located from prior job.
10. Straighten, splice wires and reconnect. Recheck.	11. Lights function normally.

Figure 2. Example Task Analysis Worksheet.

Questionnaire Survey. In order to sample a greater cross section of personnel in digital flight simulator maintenance, a questionnaire was designed and mailed to those personnel not interviewed in the field survey. The questionnaire was based for the most part on the interview format and was divided into four sections similar to those of the interview protocol of the field survey. The cover letter accompanying the questionnaire stressed that response was voluntary. There were 71 respondents to the 409 mailed questionnaires: of these, 43 contained usable data.

The format for transcribing questionnaire returns was similar to that used in the field survey, the exception being the manner in which the cues and subtasks were reported. While some of the task descriptions were edited for minor grammatical content, in most cases tasks are described in the respondent's own language.

Maintenance Data Collection Records. A third source of task data was made available to interviewer personnel subsequent to the field survey conducted at Plattsburgh AFB. Extensive Maintenance Data Collection Records (MDCRs) maintained on each of the three FB-111 simulators (two flight and one Bomb/Navigation) were made available for the task analysis. A third task analysis format was prepared to summarize these data.

Training Analysis Procedures

Concurrently with the task analyses, analyses of the two training courses afforded entry-level 341X4 and 341X6 personnel at Chanute AFB were performed. The two courses were compared under certain dimensions of commonality, and the potential use of a maintenance simulator as a training aid was investigated. A rationale subsequently was developed for restructuring both courses to maximize the teaching of the troubleshooting skills identified from the task analysis data and to best accommodate the introduction and use of a maintenance simulator.

Major attention was given to troubleshooting during the training analysis. As noted by Miller (1976), troubleshooting is perhaps the most important skill required of a good maintenance technician. In the present study troubleshooting was treated as a category of training which requires a special type of training analysis, different methods of instruction, and specialized assessments of training effectiveness. The present authors feel that troubleshooting training differs from other forms of training in that it involves a high degree of conceptual analysis and problem solving ability in addition to job-specific repair activities. Conceptual skills are far more difficult to ascertain and describe than are physical activities. Conceptual skills also require instructional methods which, in some cases, may be substantially different from those used to train motor skills.

Analyses of the 341X4 and 341X6 courses were concerned with course content and organization, nature and amount of troubleshooting training provided, and available training aids and equipment. The two courses were then compared in detail along several dimensions for similarities and differences, by topic title and hours of instruction, and by training category. A thorough analysis of the two courses is given in an unpublished Interim Report submitted earlier.

ANALYTIC RESULTS

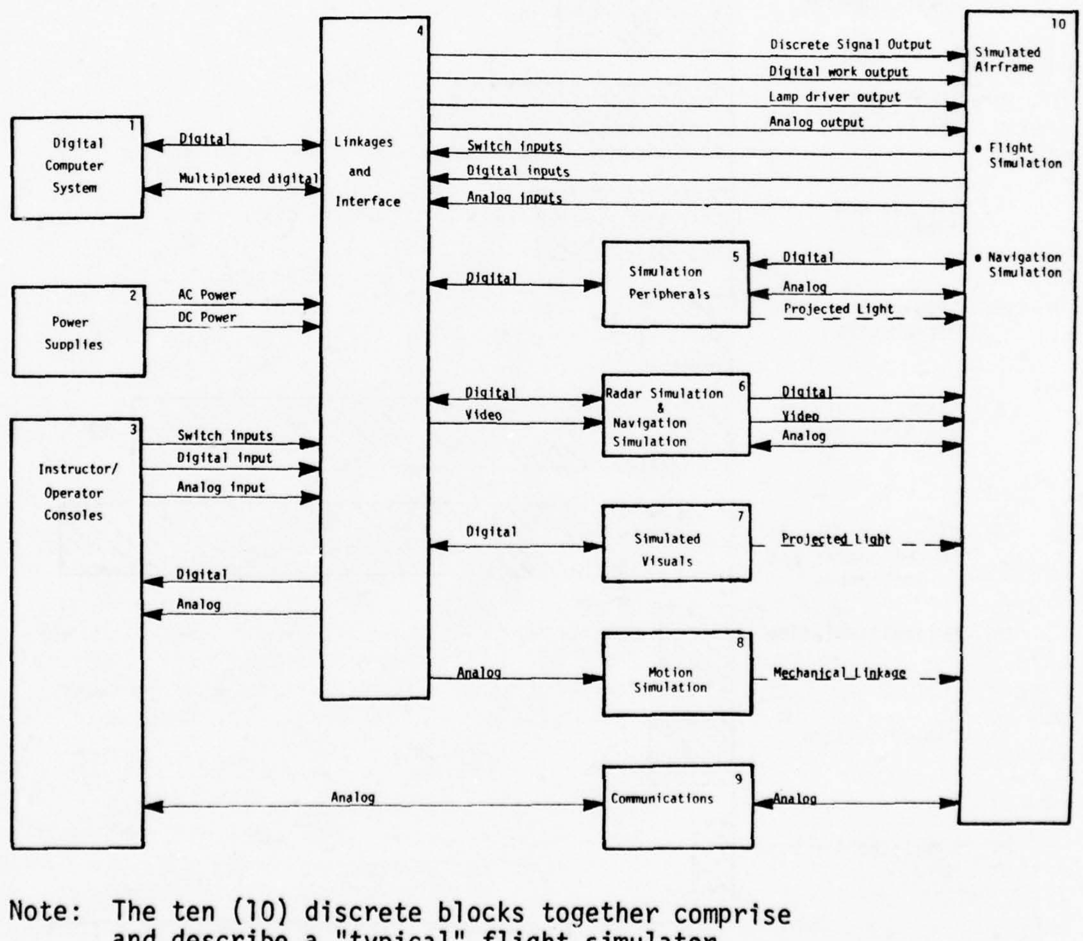
Generalized Trainer System

In order to provide a meaningful framework for data analysis, a series of block diagrams representing a "typical" flight simulator was prepared. These diagrams evolved as a product of studying the configurations of several flight simulators, and extracting the common features among them. The diagrams are in flow-chart format and were called collectively the "Generalized Trainer System." This system served three important purposes in the present study. First, it provided a way of categorizing simulator hardware, expressing functional interrelationships, and evaluating maintenance tasks. Second, the system provided a medium for interrelating job tasks from the task analyses, from the Occupational Survey tasks, from the Specialty Training Standards (STSs), and from the course requirements. Third, the system provided a logical way to organize field data on troubleshooting and other maintenance tasks. Figure 3 presents the top level block diagram of the generalized trainer system. The ten discrete blocks comprise the "top-level" simulator system. Each of the ten blocks was further subdivided in such a way that the system could be described down to the level of the lowest replaceable unit.

Task Analysis Findings

Figure 4 is a histogram of the 253 combined tasks assembled from the field survey, the questionnaire survey, and the MDCRs. The combined maintenance task frequencies are shown along the x-axis, and the 10 subsystems of the generalized trainer system are shown along the y-axis. The y-axis is non-scalar. The blocks are numbered from 1 to 10 to correspond with the blocks of Figure 2. Also, Figure 4 illustrates use of the system to organize task field data, and to relate maintenance job tasks to flight simulator hardware.

Field Data Results. A total of 66 personnel were interviewed. Forty-four 341X4 and twenty-two 341X6 personnel were interviewed; no 3-level 341X6 personnel were available for interview. The average difficulty level for all tasks was approximately 2.4. This could be interpreted as meaning that the interviewees tended to report the less difficult tasks. The average criticality level was 2.0, at the median level. The average number of personnel required to perform each task was 1.5. This figure should be interpreted with care, since safety



Note: The ten (10) discrete blocks together comprise and describe a "typical" flight simulator. The arrows and lines indicate "typical" signal flow and control functions.

Figure 3. Generalized Trainer System--Top Level.

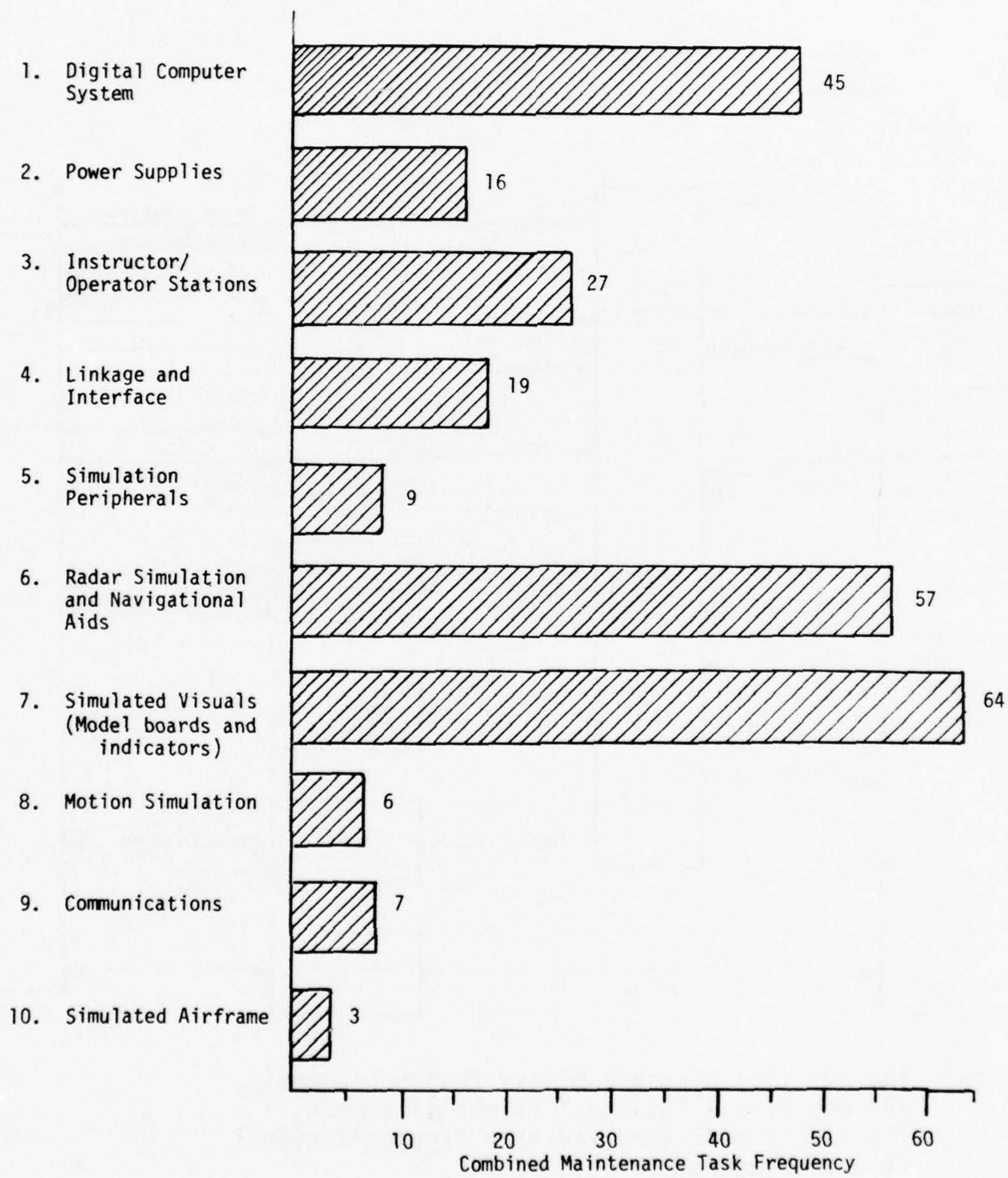


Figure 4. Summary of Task Frequency by Generalized Trainer System.

procedures dictate that two individuals be assigned to virtually every troubleshooting task. Three questions were asked of interviewees at the end of each interview concerning (a) the effectiveness of Career Development Courses (CDCs) upon job performance, (b) handling of OJT and possible improvements, and (c) general evaluation of career training in terms of curriculum, relation to job, and areas needing change.

Questionnaire Data Results. Of the 409 questionnaires mailed, 71 were returned in time to be included in this analysis. Of these 71, 43 contained usable task data. The average difficulty level for these tasks is 1.4, and the average criticality level is also 1.4. It is interesting that tasks reported by field personnel in their questionnaire response are purported to be more difficult and more critical than those obtained from field interviews. Average number of personnel to perform each task was computed as 2.0.

Response tallies were made on several of the items contained in the questionnaire. When asked how the task steps they described compared with those in the technical orders, 14 percent of those responding stated that the procedures were the same, 24 percent said similar, and 62 percent stated that procedures decribed were not contained in the technical orders. This finding corresponds with similar sentiments expressed during field interviews: Technical orders were reported to be of marginal use to field personnel in troubleshooting tasks.

To the question, "Has this task ever been performed before on the same hardware, to your knowledge?" 48 percent said yes, 36 percent said no, and 16 percent said they did not know. This question was asked to determine some measure of task frequency, so that a maintenance training simulator could incorporate similar emphasis. A related question was "Where did you learn to do this task?" Six persons responded that they learned the task in technical school; 33 responded that they learned how to perform the task in OJT; and six said that they found the procedure in the technical order.

In order to determine whether the tasks reported could be taught at technical school, personnel were asked whether they felt that the task they described could be taught at the 3-level. Eighty percent responded in the affirmative and 20 percent said no.

Finally, two open-ended questions were included to determine the general level of acceptability of a maintenance simulator either at technical school or in the field. A summary of the responses follows:

	Technical School	Field (OJT)
Simulator Beneficial	59%	70%
Simulator Not Beneficial	41%	30%

These results tend to support the acceptance and use of a maintenance training simulator, especially one to be used in the field as part of an existing OJT program.

Maintenance Data Collection Records Results. Although MDCR task data do not contain step-by-step procedures for troubleshooting, these data were included to increase the amount of information on where in the simulator malfunctions would be most likely to occur. As with the other task data summaries, each MDCR task title corresponds with one on the Occupational Survey Task List.

A general finding based on analysis of all task analytic data was that no significant differences appear to exist between 341X4 and 341X6 personnel relative to the nature of maintenance and troubleshooting task assignments commonly encountered in the field. Neither do there appear to be differences between the career fields either in terms of reported task complexity or difficulty, or in average time to troubleshoot system malfunctions. Data supporting these findings are contained in the unpublished Interim Report submitted earlier.

Training Analysis Findings

Training analysis encompassed a study of the requirements of the actual work situation, followed by a study of the degree to which the training courses supported these requirements. The analysis concentrated on troubleshooting maintenance activities. One product of the analysis was the development of six training categories as a means of organizing the training course content. They are:

- Miscellany
- Basic support skills
- General conceptual skills
- System-specific knowledge
- System-specific troubleshooting activities
- System-specific repair activities

These categories were then matched to the STS proficiency code key, and the results are shown in Table 1. The STS Proficiency Code Key indicates the type of skills to be trained and the proficiency to be attained by apprentice (-3), specialist (-5), and technician (-7) levels. It is apparent from the table that considerable similarity exists between the components of the STS and the training categories. It should be noted that the correspondence depicted is of a general nature; direct correspondence cannot be demonstrated because it is

TABLE 1

CORRESPONDENCE OF STS PROFICIENCY CODE
WITH THE TRAINING CATEGORIES

STS Proficiency Code Key		Training Category
Subject knowledge levels A. Facts B. Principles C. Analysis D. Evaluation	≈	A. Miscellany B. Basic support skills C. General conceptual skills
Task knowledge levels a. Nomenclature b. Procedures c. Operating principles d. Complete theory	≈	D. System-specific knowledge
Task performance levels 1. Extremely limited 2. Partially proficient 3. Competent 4. Highly proficient	≈	E. System-specific troubleshooting activities F. System-specific repair activities

possible to rate each training topic according to more than one STS proficiency code key.

Course Analysis Findings. The 341X4 and 341X6 courses as they were being offered in the summer of 1978 were the subject for analysis. The 341X4 course consists of approximately 481 total instructional hours, of which 93.5 are devoted to performance training. The 341X6 course consists of about 549.5 instructional hours, of which 195 are devoted to performance training. The courses can generally be characterized as being predominantly classroom instruction, combined with performance exercises and optional study material.

Table 2 shows the composite training emphasis for the two courses by Specialty Training Standard. This analysis shows that the majority of training time is devoted to only two of the 20 STS requirements: digital computers, and aircrew training devices, circuit analysis, and alignment. The majority of the STS requirements receive less than 5% of the total training time.

Table 3 illustrates the relative training emphasis of the two courses with respect to the six training categories previously described. From this table it is apparent that course instruction emphasized system-specific knowledge and basic support skills. (The term "system-specific" is used here to mean specific to flight simulators, but does not refer to actual simulators in the field.) This table also shows that little training was given in the area of system-specific troubleshooting.

Comparison of 341X4 and 341X6 Courses. The 341X4 course was designed to train personnel to maintain digital flight simulators, while the 341X6 course was designed to train personnel to maintain navigation/tactics simulators. Navigation/tactics simulation is often done in conjunction with flight simulation, using the same simulated airframe. Since field data indicated that distinctions between the two specialties are rarely made in actual maintenance assignments, and since the two courses share many common instructional blocks, a comparison was made to determine the degree of overlap in terms of course content.

Table A-1, in Appendix A, summarizes the similarities and differences between the 341X4 and 341X6 courses ordered by training category. It is apparent from this table that the two courses have a high degree of commonality, and this commonality should be greater with a more appropriate treatment of general conceptual skills.

Figure A-1 compares the relative amount of training time for the 341X4 and 341X6 courses, ordered by the generalized trainer system. This figure shows that the 341X4 and 341X6 courses both emphasize the digital computer system and associated linkage and interface subsystems over other aspects of the simulator. The major difference

TABLE 2

COMPOSITE TRAINING EMPHASIS BY SPECIALTY TRAINING STANDARD

Rank Order	Special Training Standard (STS)	% Total Course Hours
1	Digital computers	37
2	Aircrew training devices, circuit analysis, and alignment	25
3	Maintenance of aircrew training devices	9.4
4	Operation and use of aircrew training devices, circuits, and components	6.4
5	Tools and test equipment	5
6	Basic instrument flying procedures	3.7
7	Principles of navigation and tactics	3.5
8	Technical Orders	2
9	Maintenance management, inspection systems, and forms	2
10	Radio navigation procedures	1.8
11	Aircrew training devices (ATD) configuration	1
12	Operate aircrew training device consoles	1
13	Aerodynamics of flight	.8
14	Supply responsibilities	.5
15	Class I training equipment inventory, utilization and status reporting	.5
16	Security	.4
17	Career ladder progression	.3
18	Aircrew training devices safety	.2
19	Supervision and training	0
20	Electronic principles applicable to tasks listed in this STS	0

TABLE 3

COURSE CONTENT SUMMARIZED BY TRAINING CATEGORY

Training Category	% Total Training Hours 341X4 Course	% Total Training Hours 341X6 Course
Miscellany	2	1
Basic Support Skills	30	21
General Conceptual Skills	15	7
System-Specific Knowledge	43	61
System-Specific Troubleshooting Activities; System-Specific Repair	10	10

between the 341X4 and 341X6 courses is that the 341X6 course puts far more emphasis on the topics of "Radar Simulation and Navigational Aids" and "Simulated Visuals." The 341X6 course also devotes more training hours to the digital computer system.

Table A-2 summarizes the common training topics for both the 341X4 and 341X6 courses. This analysis indicates that elements of the simulator system having the most overlap between the 341X4 and 341X6 courses are the digital computer system, power supplies, and linkage and interface subsystems.

Troubleshooting Training Potential of the 341X4 and 341X6 Courses. Analysis of the 341X4 and 341X6 courses indicated that they did not stress troubleshooting skills of the type most often required of 3-and 5-level personnel in the field as indicated by the task analysis. Under the assumption that these skills are to receive increased emphasis during technical school training with the addition of a maintenance simulator, changes to the existing courses could be achieved in one of several ways. Four possible approaches are (a) restructure according to training category, (b) reemphasize certain blocks according to training category, (c) perform major course changes, and (d) combine the 341X4 and 341X6 courses. Each of these approaches is considered separately below.

Restructure According to Training Category. This alternative would entail restructuring the existing 341X4 and 341X6 courses according to the training categories. This approach is a "minimum" approach, and the incorporation of a maintenance simulator into this restructured training would have a minimal impact. However, restructuring of the course could provide a logical basis for more comprehensive restructuring approaches, and suggests the use of various training approaches throughout the course. "Classroom instruction" and "test equipment and tools" could involve the use of both simulation training and other forms of training such as classroom instruction, graphic simulation, part-task trainers, and job performance aids.

Table B-1 in Appendix B shows how the 341X4 course might be restructured according to training category. Suggested training approaches are listed to the right of each training topic. The first three training categories cover 224 hours of instruction, while the last two categories cover 257 hours of instruction. The first half of the course is concerned with the basic skills and general knowledge. Thus, the first half of the course is not unique to the 341X4 specialty, but could be applied to the 341X6 course equally well. The second half of the course is devoted to system-specific training, and is unique to the 341X4 course. This half could be modified to accommodate a specific skills maintenance simulator.

Table B-2 in Appendix B shows how the 341X6 course could be restructured according to training category. The 341X6 course structure is essentially similar to that of the 341X4, except that the first three categories cover 161 course hours, while the last two categories cover 388.5 hours of instruction. The 341X6 course, then, places less emphasis on basic and general skills and considerably more emphasis on system-specific knowledge and system-specific troubleshooting activities.

This analysis suggests that two courses could be taught in a logical progression, each major instructional group associated with a specific instructional approach. "Miscellany" and "Basic Support Skills" both are associated with classroom instruction. The sections on hand tools, test equipment, and application of test equipment could be placed at the end of this segment. The next major instructional group would be "General Conceptual Skills;" this group could incorporate both "Test Equipment and Tools" and a maintenance simulator. This training group would continue to employ classroom instruction, but could provide considerable hands-on experience with real tools, real test equipment, real digital computers, actual programming experience, and an opportunity to work with real-time simulation concepts and procedures using a generic simulator.

Reemphasize Certain Blocks According to Training Category. This alternative would entail a major restructuring of the courses, giving new emphasis to new instructional approaches and greater use of simulation training techniques. Major revision of the 341X4 and 341X6 courses could result in a strong emphasis on training troubleshooting skills. Employing the training category scheme above, the training topics currently listed under general conceptual skills may be eliminated, and new topics covering component failure and general troubleshooting strategy may be substituted. The system-specific knowledge and system-specific troubleshooting activities could be taught with respect to the dynamic system of which they are a part. The generalized trainer system could be used as a method for organizing system-specific knowledge and as a basis for studying the functional interaction of the system to be maintained.

Perform Major Course Changes. The third alternative involves major restructuring of the 341X4 and 341X6 courses by considering the introduction of individualized and self-paced instruction to increase instructional efficiency and to reduce training time. Organizing the course according to training category would place most of the classroom instruction at the start of the course. Following a fixed duration of classroom instruction, the course could include a number of modules of self-paced, individualized instruction to be completed by each student before graduation. This period of self-paced instruction could make extensive use of simulation training. Modules of instruction could be completed in any order desired by the student, consistent with scheduling and administrative considerations.

Combine 341X4 and 341X6 Courses. There are two reasons to consider combining the 341X4 and 341X6 courses. First, there is a large body of basic support skills and general conceptual skills common to these two courses. The test equipment, tools, and generic maintenance simulator could support training common between these two courses. Second, all system-specific training could be done with individualized, self-paced instruction which could be specific to each system. Graphic information could be stored on microform or electronic memory, in easily replaceable cartridges, cassettes or disks. There would be no problem for two, three, or even more flight simulator systems to be trained separately during a single class period by means of graphic simulation.

Major restructuring of the 341X4 and 341X6 courses could also be accomplished by teaching all basic support skills and general conceptual skills in technical school at Chanute, and training all system-specific troubleshooting and system-specific repair activities in the field. This approach could present a number of advantages. First, resident training at Chanute would include only general training, concentrating on the use of test equipment, the logic of simulation training, computer programming, hands-on training in the use of the digital computer, and the process of control associated with digital simulators. The resident training could also include the topics of how components fail, how to detect component failure, how to measure weak or defective components, and the likelihood of component failure; general troubleshooting strategies and cascading faults; and methods for verifying system operation once a repair has been made.

Field training, in this case, could be primarily devoted to system-specific knowledge, system-specific troubleshooting, and system-specific repair activities. With the addition of one or two individualized self-paced maintenance simulators, the student could learn while on the job. Each field operation could utilize graphic simulation of its particular simulator, and changes in simulator configuration could be incorporated into the trainer with minimum delay. Also, actual simulator malfunctions could be added to the maintenance trainer courseware to make the training problems more congruent with actual job tasks.

DEVELOPMENT OF MAINTENANCE SIMULATOR CONCEPTS

The evolution of thought leading to the specific maintenance simulator concepts described in this study was a complex process, combining theoretical considerations with the practicalities of implementation and use, and supported in detail by the results of the task and training analysis data. This section attempts to trace the primary factors which contributed to the development of the specific maintenance simulator devices recommended for supporting Air Force flight simulator maintenance training.

Theoretical Considerations

The present authors feel that different simulation training approaches may be appropriate for different categories of behavior. Those behaviors required of technical school students are not necessarily the same as those required of experienced field maintenance personnel, therefore, different needs for maintenance simulators may exist. Further, troubleshooting was identified as a form of problem solving skill which does not require high fidelity simulation, in fact, physical fidelity may be of minor importance in terms of promoting training effectiveness. This is in contrast to psychomotor skill learning where higher levels of physical fidelity are generally required.

The research of Harlow (1967) on "learning-how-to-learn" suggests that the learning of many similar fault isolation tasks in flight simulator systems may result in the gradual development of superior problem solving ability, and that this ability can be transferred effectively to a job situation. The proposed maintenance simulator concepts were based on the notion that broad problem-solving experience is appropriate for the development and transfer of problem solving ability required for system troubleshooting of digital flight simulators.

The notion that basic support skills involve psychomotor skills best learned by "hands-on" training, combined with a desire to present this training within the context of a flight simulator configuration easily grasped by inexperienced trainees, led to the development of a simulator concept which was a real working model of a flight simulator but on a greatly reduced physical scale. This type of trainer could permit operation of the equipment, loading of computer programs, stepping through programs, tracing signals with real test equipment,

measuring the flow of signals, and observing the operation of a dynamic, functioning system. Trainer documentation would consist of far fewer pages than that usually associated with actual flight simulators, and could be easily mastered. Flow charting of the trainer computer program would also be less complicated and more easily mastered. The trainer would also have real diagnostic programs which could be used by the trainees.

The requirement to produce troubleshooting training for field use, which would provide instruction in both general flight simulation and in a wide variety of specific flight simulators, led to the concept of a conceptual trainer which used some form of interactive graphic media. A "graphic" type trainer could be used to represent a variety of specific flight simulators, and further, could provide extensive practice over many troubleshooting problems. The use of a graphic simulator also presented the possibility of incorporating an additional element of instructional capability to further enhance the training of system understanding: this instructional element may be called "functional flow analysis," and is based upon the analysis of the simulator system into functional groups, or subsystems, and then arranging these subsystems in a "logic tree" arrangement. The authors feel that this method of organizing and presenting system information will increase system understanding on the part of the trainees.

Graphic trainers offer other possibilities for increased instructional capability. For example, graphic representation may eliminate or suppress extraneous detail, focus attention on important objects or conditions, provide performance feedback or knowledge of results, employ compression or expansion of time frames, and record measurements of student performance. Instructional topics which could be addressed in a graphic troubleshooting trainer could include simulator purpose and design approach, documentation and technical orders, system hardware and configuration, system operation, subsystems function and operation, malfunction analysis, input/output relationships, and details of system operation down to the level of the replaceable unit.

Another theoretical consideration which guided the development of the graphic trainer concept was the notion that simultaneous visual comparisons would aid concept formation and significantly increase training effectiveness. Simultaneous stimulus presentations have been used extensively in animal training studies and have proven to be superior to successive presentations in discrimination studies. This theoretical notion was translated into a trainer requirement that the simulator have a dual visual display, and that alternative "views" of the system be readily available. For example, system representation could be presented simultaneously with test and measurement data from the system. Explanatory information could also be available simultaneously with the test and measurement data for rapid alternation of attention and association. While it is true that this concept is an

hypothesis awaiting experimental verification, it does provide a trainer requirement which sets this device apart from many other approaches which use a single display screen.

Practical Considerations

The development of maintenance simulator concepts was also dictated by many considerations of a practical nature, as well as from specific suggestions made by Air Force personnel representing both the developing and using commands. These are summarized below:

- The maintenance simulator concepts must be capable of supporting both the 341X4 and 341X6 specialties at the 3, 5, and 7 skill levels. Therefore, the concepts must be suitable for use by personnel possessing wide variation in knowledge and skill.
- The concepts must incorporate a multi-system capability to support troubleshooting training in all existing Air Force digital flight simulators as well as those likely to be built in the near future.
- The concepts must be capable of convenient integration into existing training programs, and must support group training in technical school and individualized on-the-job training in the field.
- The simulators must be of relatively low development cost, and should utilize lower fidelity requirements where this can be done to lower costs without sacrificing training effectiveness.
- The design of the simulators must utilize state-of-the-art equipment and technology.
- The simulators must be so designed that Air Force instructors and supervisory personnel can do their own courseware authoring and development.
- Finally, the simulators must serve the dual role of supporting training in the 341XX career field and serving as a research vehicle to support future study efforts in the area of maintenance training simulation.

Implications of Analytic Results

The training and task analysis data served to define both the environment in which the maintenance simulators would be employed and the subject matter for troubleshooting training, both of which contributed to further development of the concepts. The task data support

simulator concepts which stress training in the areas of digital computers, radar simulation and navigational aids, and simulated visuals. Data obtained provide adequate samples of typical tasks in varying degrees of complexity, to accommodate each skill level. Most importantly, task data support the need for and acceptance of maintenance simulators both in technical school and in the field.

Analysis of the content of the technical school courses indicated that three major types of knowledges and skills should be taught: general skills, system-specific knowledge and troubleshooting skills; and system-specific repair procedures. This further suggested the development of three separate maintenance simulators to support each of these content areas.

Analysis of training needs, and the anticipated integration of simulators within existing maintenance training programs, indicated that no single device could support all the needed training for both school and field detachment use. Several separate training devices appeared to offer the greatest promise for maximum training effectiveness, least training cost, and adaptability to both present and future training needs. A generalized trainer could be used in the school to support group training on concepts and tasks which could be generalized to a wide variety of actual flight simulators. A graphic trainer would be a multiple-system trainer, and could be used to support individualized instruction for both school training and for field training at specific simulator sites. Graphic trainers could be updated easily to accommodate changes in the flight simulator configuration. Also, completely new simulator systems may be represented on the graphic simulator by developing new software. Specific repair procedures could be handled by another type of device which could be considered a form of Job Performance Aid (JPA). This type of simulator-trainer could be portable, contain step-by-step repair procedures for a specific flight simulator, and could be used in conjuction with actual system equipment either for training or to assist with actual repair operations.

Summary of Recommended Concepts

A general conclusion developed during the analytic efforts was that separate part-task trainers would be a reasonable design solution. These trainers would be (a) a basic skills trainer having wide generalizability, (b) a system-specific knowledge and conceptual troubleshooting skills trainer, and (c) a system-specific repair procedures trainer.

Basic Skills Trainer. This maintenance simulator concept was conceived of as a small replica of a digital flight simulator and a digital navigation/tactics simulator. This trainer is designed to provide students with hands-on experience with digital computers, computer programming, and control functions typical of modern digital

flight simulators. The configuration represents only the roughest analog of actual digital flight simulators.

Figure 5 shows one concept of this "scaled-down simulator." The trainer utilizes two small micro-computers in a real-time multiprocessing configuration. The instructor station contains an executive program and can provide control and supervision over the two trainer stations. The trainer is designed to permit students to become actively involved in working with digital computers, measuring signal flow, and seeing the effect of computer commands on the display equipment. The pilot and navigator stations contain only a limited number of switches, displays, and control equipment, but these should represent the most important aspects of each flight simulator. The entire trainer system is small and compact so that all aspects of the simulation process are readily observable. Test points are provided so that students can measure the signal flow with actual test equipment. The trainer could accommodate up to six students and one instructor.

The "scaled-down simulator" is designed to train basic support skills and general conceptual skills. The trainer will aid students in understanding the concept of how digital computer systems are used to produce simulated functions. Students can develop actual digital computer programs to produce simulated flight conditions. Programming may involve the use of Boolean algebra, real-time programming concepts, and the operation of multi-processing systems. Students will also be able to use digital test units, voltmeters, and oscilloscopes to measure signal flow. The system will permit students to follow control and signal flow from the digital computer through the linkage and interface system, through the simulated subsystems, and to the simulated airframe. This entire chain of events will be observable within the space of a few feet.

The "scaled-down simulator" has not specifically been designed to be a troubleshooting trainer. However, this trainer does offer a unique capability for training with respect to computer program design errors. Introducing programming errors into the system will not damage the computer or control system. Furthermore, training students to go through existing programming to track down logic errors and timing problems is a necessary and important part of their skill preparation.

The "scaled-down simulator" could be a valuable and important training device for the 341X4 and 341X6 courses. This system would provide actual hands-on experience with the most important, complex, and difficult-to-understand aspect of the system to be maintained, the digital computer system. The trainer will permit actual tests and measurements of signal flow and conditions. The system will permit each student to develop and work with computer programs which could be used to control simulated flight conditions and to examine the effects of flaws in this programming. Since the trainer does not attempt to

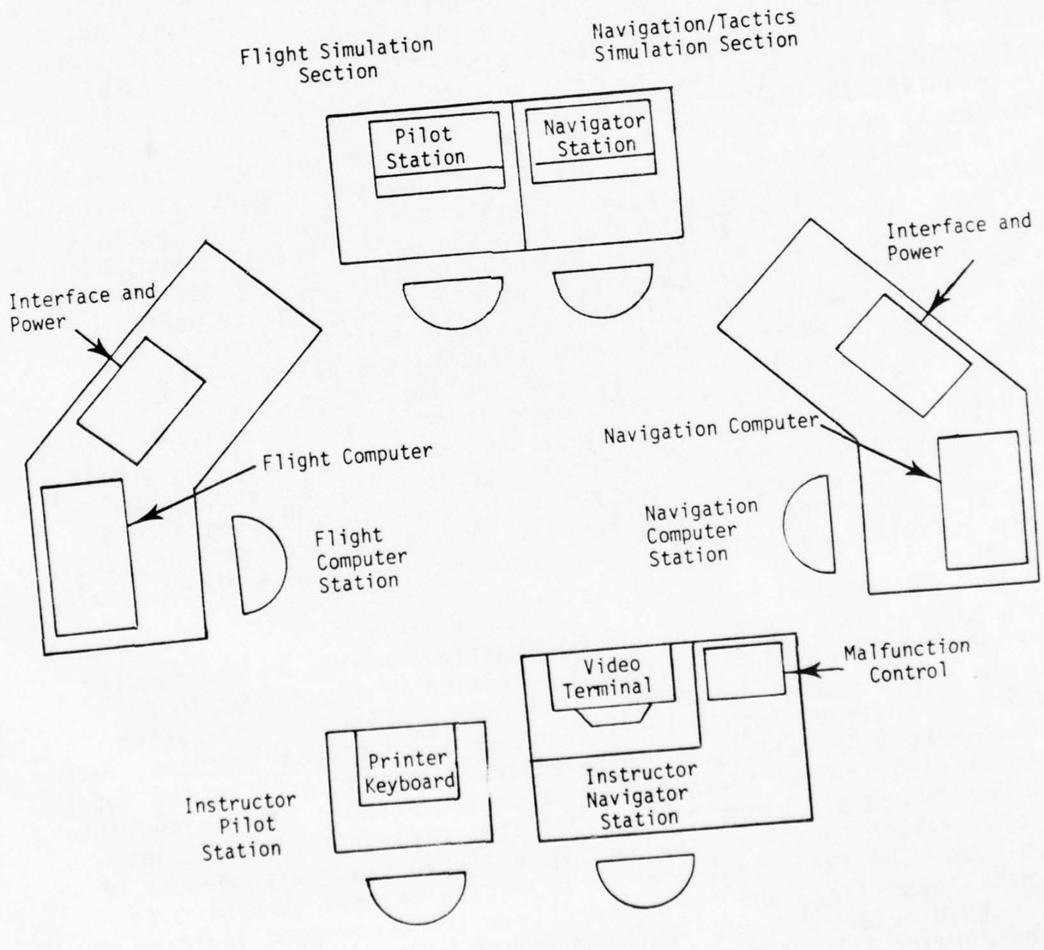


Figure 5. Concept of a Scaled-Down Simulator for Training Basic 341X4 and 341X6 Maintenance and Operations Concepts.

duplicate a specific system, modifications will not be needed to keep up-to-date with newer aircraft flight simulators.

A functional specification detailing the requirements of this maintenance simulator concept was developed and delivered to the Air Force Human Resources Laboratory, Technical Training Division (AFHRL/TT).

Specific Skills Troubleshooting Trainer. The troubleshooting trainer was selected as the training device to be developed to support the learning of troubleshooting skills for specific digital flight simulator systems. The trainer was to provide for individualized, self-paced instruction, and the device is expected to be located and used at a specific flight simulator site. The trainer is a multi-system trainer. That is, the same physical device is capable of representing several existing flight simulator systems, and also capable of adaptation to future flight simulator systems. The trainer is to be a conceptual trainer, and is designed to support the development of system knowledge, system understanding, and troubleshooting ability. The trainer provides an opportunity for extensive practice over all aspects of the flight simulator system. Opportunity is provided for going through the process of signal tracing, selecting and locating test points, determining what test equipment to use, evaluating signals and waveforms, and isolating systems where faults occur. Skills which may be developed include recognizing faults, learning the identification and nomenclature of system hardware, using technical orders and other technical documentation, isolating specific faults, determining appropriate repair procedures, and verifying whether proper system operation has been restored following a repair action. The trainer does not, however, attempt to deal with physical repair activities or with the procedures associated with these repair activities.

A central feature of the troubleshooting trainer is the requirement for "front end" analysis and description of the system to be maintained in terms of functional flow logic. That is, the system hardware is analyzed into a limited number of functional systems, each system having a specific goal to be achieved with respect to the total system mission. These functional systems are further sub-divided into a limited number of subsystems so that the complete digital flight simulator system can be represented by a "logic tree" arrangement of subsystems. The functional goal or objective of each subsystem is succinctly described, and these objectives are documented in terms of input-output relationships. This method of system decription enhances the instructional capability of this trainer by teaching system logic directly. The user begins each troubleshooting problem from the perspective of the total system configuration, and then begins to analyze which subsystems are most likely at fault. The flow of signals or control functions may be followed more easily because of this method of system description. Signal tracing theory, then, becomes a

workable troubleshooting strategy for troubleshooting large military systems. The "logic tree" arrangement of logic diagrams permits the user to pinpoint the precise subsystem where the fault occurs. Symbolic replacement of the defective subsystem may be followed by verification of normal system operation. Thus, training may proceed according to a whole-part-whole sequence. Training may also be provided over all aspects of simulator operation by having one or more malfunctions within each simulator subsystem. Training must be done on a problem-by-problem basis. The process of solving many troubleshooting problems will develop system-specific troubleshooting skills as well as increase overall system knowledge and understanding. Repeated problem-solving will also support the development of general problem-solving ablity. Problem-solving situations are inherently motivating and act to increase attention and involvement in the learning process. The training situation is also designed so that the user must request the information before it can be received, and this also acts to support motivation and involvement in the learning process. Furthermore, the user is permitted to pursue the wrong paths and to make mistakes. The training device could be designed to permit the user to obtain help or assistance during a session by requesting functional descriptions of each subsystem or explanatory material associated with test and measurement data. This help or assistance may also refer the user to sections in the system technical orders or other technical documentation.

Figure 6 shows an artist conception of the troubleshooting trainer work station. The training device itself includes a dual random access visual information retrieval system which is under microprocessor and keyboard control. Instructional elements could be designed to represent single troubleshooting problems, and the information required for each lesson may be stored on microforms or computer memory, along with any other necessary media. Instructional elements could be packaged as independent packets, and the user could be able to select a suitable packet, insert it into the device, and work through a troubleshooting problem. The dual visual display system can permit the simultaneous presentation of block diagrams/schematics/illustrations on one side, and symptoms, test results, and help or assistance on the other. Microprocessor or computer control can be used to produce performance records, both for user benefit and for potential research applications.

A functional specification detailing the requirements of this maintenance simulator was developed and delivered to AFHRL/TT.

System-Specific Repair Procedures Trainer. This concept is conceived of as a microfiche viewing system which can provide step-by-step instructions to assist in repair activities. This system could be taken right to the site of a specific task and used for actual field repairs. Additionally, it could be used with part-task trainers for training purposes.

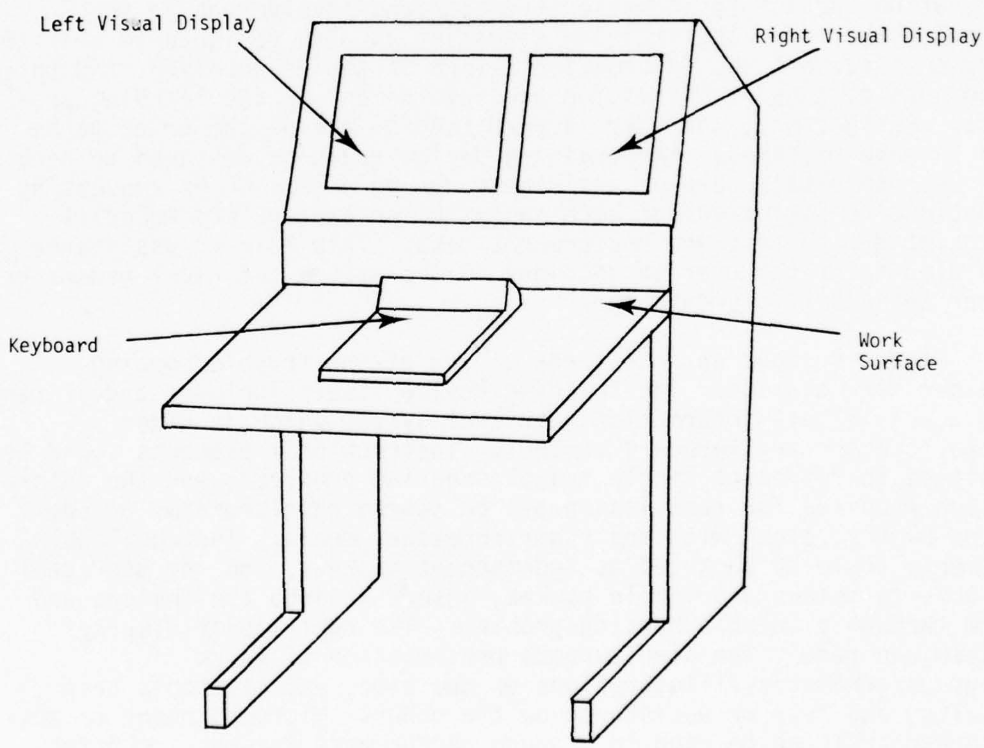


Figure 6. Work Station of Troubleshooting Trainer.

The data base for the repair activities aid could be developed from existing technical orders, and the repair tasks could be structured according to the generalized trainer system previously described. The use of the generalized trainer system would also permit a logical translation from technical training course material to actual repair tasks. Repair tasks could be selected to represent the entire system to be maintained. Tasks could be evaluated for inclusion on the basis of frequency, difficulty, importance to the system mission, and upon safety considerations. Presentation of the instructional content could be accomplished near state-of-the-art in terms of job performance aid technology.

A functional specification was not developed for this device.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based upon analyses of maintenance tasks and technical training in the 341XX career field, and upon an effort to develop training device concepts suitable for supporting the identified maintenance training needs within this career field.

Conclusions

Training Needs. Analyses of the 341XX career field included the types of maintenance tasks performed on the job, the courses providing supporting training, and adjunct hardware. These analyses led to the following conclusions concerning training needs:

1. Course material needs to be presented within the context of digital flight simulators and their functional configuration. The purposes of digital flight simulators should be presented first, and subfunctions and components presented in terms of how these elements contribute to the operation of flight simulators, using the "whole-part-whole" approach.

2. Instruction needs to be given on the way in which aircraft performance is simulated by digital flight simulators. Instruction should present the concept of collecting flight performance data on the aircraft to be simulated, converting these data into flowcharts, and translating this information into digital computer programs. Instruction also needs to be given on how digital computers act on these computer programs, and how the computer and computer programs work in conjunction with other system elements to produce simulated flight.

3. Instruction needs to be given on the concept of system troubleshooting as opposed to component troubleshooting. Trainees need to be taught how to differentiate between system hardware and computer software as causes of system malfunctions. Trainees must be taught to follow computer programs and other system documentation, locate suitable test points, determine the types of tests and measurements needed, evaluate test and measurement data, and isolate the causes of system malfunctions.

4. There is a need for functioning hardware (simulated or actual), configured as a digital flight simulator, with which students can learn the general knowledges and practice the basic skills required to maintain digital flight simulators. Components should include or simulate state-of-the-art digital computers, computer peripherals, linkage and interface equipment, and simulated aircraft components. This equipment should be configured as a digital flight

simulator but does not need to be a full scale simulator. The training equipment should permit turning the system on, running readiness checks, loading computer programs, running a simulated flying mission, and diagnosing improper system operation. Real test equipment should be used for signal tracing and evaluation of the functioning flight simulator system.

5. A new training emphasis is needed to provide detailed training on specific digital flight simulator systems likely to be encountered on the job. Specific system training should include a knowledge of the overall flight simulator configuration, the subsystems employed, the function and interrelationship of these subsystems, and detailed knowledge of how the simulator functions when it is working properly. Increased emphasis should also be given for training troubleshooting skills on specific digital flight simulator systems. Troubleshooting training should cover all major aspects of the simulator system to be maintained so that trainees will have a fundamental understanding of the system they will be expected to maintain on their job.

Recommendations

The task analysis and training analysis results, the trainer concepts developed, and the conclusions of this study led to the following recommendations:

1. Prototype trainers of the type described in this report should be built for support of both generalized applied skills and for system-specific troubleshooting skills.

2. These devices, when completed, should be used to support the learning of maintenance skills within the 341XX career field.

3. These devices also should be used to support research studies in the area of maintenance training.

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APPENDIX A

COMMON TRAINING TOPICS FOR 341X4 AND 341X6 COURSES
LISTED BY TRAINING CATEGORY

TABLE A-1. SUMMARY COMPARISON OF 341X4 AND 341X6
BY TRAINING CATEGORY

X-4 Course	Unique Hours	Common Hours
A. Miscellany	0	7
B. Basic Support Skills	6	139
C. General Conceptual Skills	64	8
D. System-specific Knowledge	42	172
E. System-specific troubleshooting activities	0	43
	112 Total	369 Total
	23% of course	77% of course

X-6 Course	Unique Hours	Common Hours
A. Miscellany	0	8
B. Basic Support Skills	4	143
C. General Conceptual Skills	36	2
D. System-specific Knowledge	162	171
E. System-specific troubleshooting activities	0	23
	202 Total	347 Total
	37% of course	63% of course

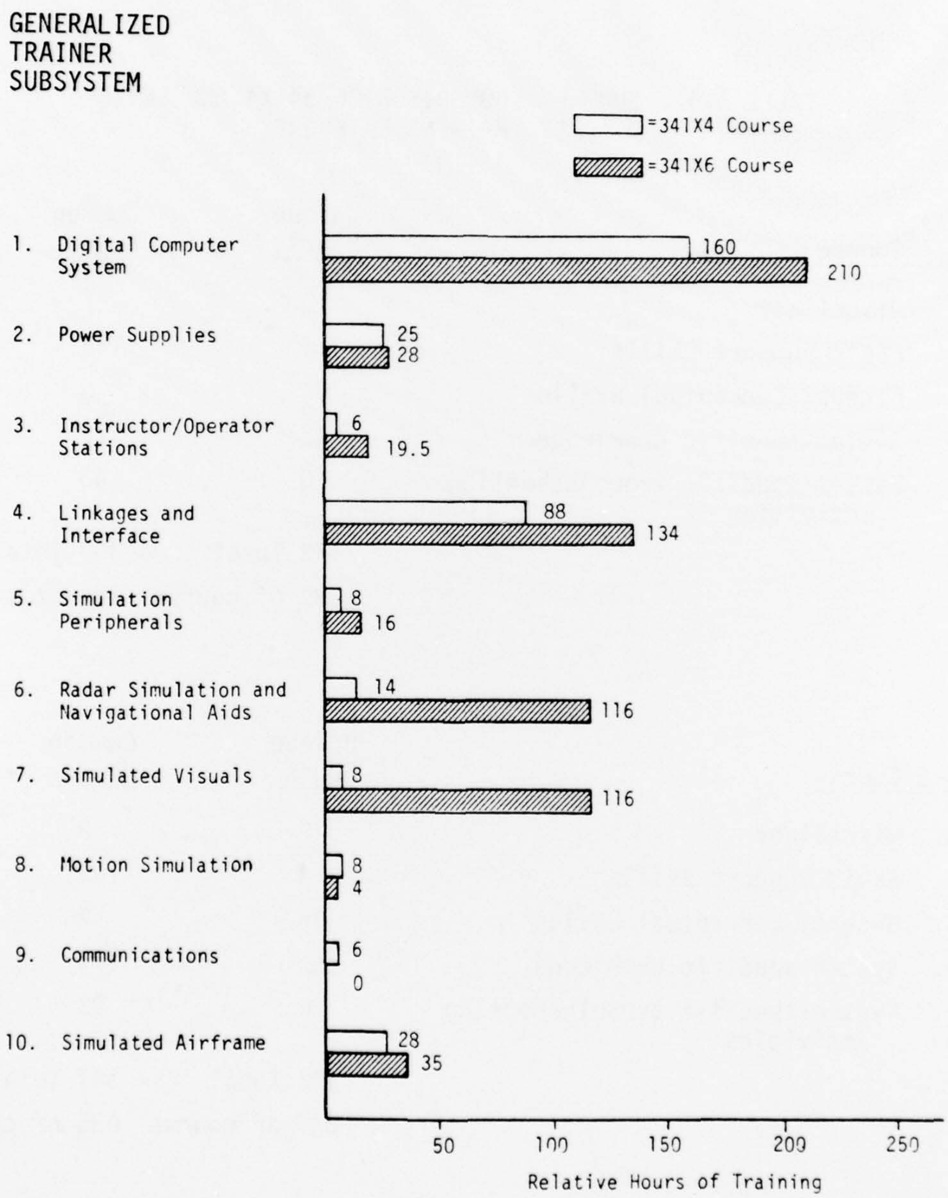

Figure A-1. Summary of 341X4 and 341X6 Course Similarities and Differences, Ordered by Generalized Trainer System.

TABLE A-2. SUMMARY OF COMMON TRAINING TOPICS FOR 341X4 AND 341X6 COURSES LISTED BY GENERAL TRAINING SYSTEM

1. Digital Computer System	X4 Course Block	X6 Course Block
AC and DC Power, Operational Checks and Alignments	IV-4	II-3
AC Amps, DC Operational Amplifiers	V-1	III-1,2
Discrete Logic Elements	VII-1	VIII-1
Memory and Timing Elements	VII-2	VIII-2
Integrated Circuits & Functional Blocks	VII-4	VIII-4
Memory Systems	VIII-1	IX-1
CPU Control and Timing	VIII-2	IX-2
Programming/Diagnostics	VIII-4	IX-3
Cyclic Computer Configuration	IX-1	X-1
Central Processor Unit, Operation and Programming	IX-2	IX-2
On-line Utility Diagnostics	IX-3	X-3
Peripheral Equipment	X-1	XI-1
2. Power Supplies		
Power Generation Equipment	IV-1	II-1
AC and DC Distribution	IV-2	II-2
AC and DC Power, Operational Checks and Alignments	IV-4	II-3
3. Instructor Operator Consoles	None	

Table A-2 (Cont'd)

	X4 Course Block	X6 Course Block
4. Linkages and Interface		
AC and DC Power, Operational Checks and Alignments	IV-4	II-3
AC Amplifiers, DC Op. Amplifiers	V-1	III-1,2
Discrete Logic Elements	VII-1	VIII-1
Memory and Timing Elements	VII-2	VIII-2
Integrated Circuits & Functional Blocks	VII-4	VIII-4
5. Simulation Peripherals		
Peripheral Equipment	X-1	XI-1
6. Radar Simulation and Navigational Aids	V-2	III-8
7. Simulated Visuals		
Servo Systems	V-2	III-8
8. Motion Simulation		
Servo Systems	V-2	III-8
9. Communications	None	
10. Simulated Airframe		
Servo Systems	V-2	III-8

APPENDIX B

REORGANIZATION OF THE 341X4 AND 341X6 COURSES
BY TRAINING CATEGORY RELATED TO
POSSIBLE TRAINING APPROACHES

TABLE B-1. REORGANIZATION OF THE 341X4 COURSE BY TRAINING CATEGORY RELATED TO POSSIBLE TRAINING APPROACHES

Training Category	X-4 Course Topic	Generalized Trainer	Hours Training	Classroom Instruction	Test Equipment and Tools	Scaled-Down Simulator	Troubleshooting Trainer
A. Miscellany	I-1. School Orientation		2	CI			
	I-3. Career Duties and Progression		1	CI			
	I-4. Security		2	CI			
	II-6. Measurement and Critique		2	CI			
			7 TOTAL				
B. Basic Support Skills	I-5. Flight Training Devices Safety		1	CI			
	I-6. Technical Orders		9	CI			
	I-7. Air Force Supply System		3	CI			
	I-8. Class I Trainer Equipment Inventory Utilization and Status		1	CI			
	I-9. Use and Care of Handtools		2		TE		
	I-10. Introduction to Maintenance Management and Inspection System		10	CI			
	II-5. Application of Flight Publications		6	CI			
	IV-3. Test Equipment		13		TE		
	VI-1. Number Systems and Mathematical Operations		18	CI			
	VI-2. Boolean Algebra		20	CI			
	VII-3. Integrated Circuit Parameters and Package		4	CI			
	VIII-3. Flow Charts		5	CI			
	-4. Programming Concepts		47	CI			
	X-4. Application of Test Equipment		6		TE		
			145 TOTAL				

Table B-1 (Continued)

C. General Conceptual Skills	II-1. Aerodynamics of Flight		8			SDS	
	-2. Performance, Control and Navigation Instrument		6			SDS	
	-3. Radio and Telephone Procedures		4			SDS	
	-4. Navigation Procedures		14			SDS	
	III-1. Console Controls and Cockpit Familiarization		8			SDS	
	-2. Attitude Instrument Flying		8			SDS	
	-3. Instrument Takeoff, Climb and Approach		8			SDS	
	-4. Flight Maneuvers		8			SDS	
	-5. Simulated Mission Profile		8			SDS	
			72 TOTAL				
D. System-Specific Knowledge	I-2. Flight Simulator Configuration	ALL	3				TT
	IV-1. Power Supply Circuits	2	12				TT
	-2. AC and DC Power Distribution	2	5				TT
	V-1. Amplifiers, Detectors, Oscillators	1,4	8				TT
	-2. Servo Systems and Signal Sources	6,7,8,10	8				TT
	-3. Control Loading and Motion Systems	8,10	14				TT
	-4. Indicating Systems and Switches	3,6,9,10	6				TT
	VII-1. Discrete Logic Elements	1,4	8				TT
	-2. Memory and Timing Elements	1,4	22				TT
	-4. Integrated Circuits and Functional Blocks	1,4	36				TT
	VIII-1. Memory Systems	1	12				TT
	-2. Control and Timing	1	12				TT
	IX-1. Cyclic Computer Configuration	1	8				TT
	-2. Central Process Unit Operation and Programming	1	24				TT
	-3. On-line Utility Diagnostics	1	6				TT
	X-1. Peripheral Equipment	1,5	8				TT
	-2. Interface/Linkage Systems	4	8				TT
	-3. Computer and Peripheral Diagnostics	1	8				TT
			208 TOTAL				

Table B-1 (Continued)

E. System-Specific Troubleshooting Activities							
	IV-4. Operational Checks and Alignments	1,2,4	8				TT
	VII-5. Troubleshooting Techniques	ALL	8				TT
	X-5. Perform Schedule Inspection	ALL	6				TT
	-6. Troubleshoot, Adjust, Repair	ALL	<u>27</u>				TT
			49 TOTAL				

TABLE B-2. REORGANIZATION OF THE 341X6 COURSE BY TRAINING CATEGORY RELATED TO POSSIBLE TRAINING APPROACHES

Training Category	X-6 Course Topic	Generalized Trainer	Hours Training	Classroom Instruction	Test Equipment and Tools	Sealed-Down Simulator	Troubleshooting Trainer
A. Miscellany	I-1. School Orientation		2	CI			
	-8. Security		2	CI			
	-9. Career Duties and Progression		2	CI			
	IV-2. Measurement and Critique		2	CI			
			8 TOTAL				
B. Basic Support Skills	I-2. Flight Training Devices Safety		1	CI			
	-3. Oscilloscope		13		TE		
	-4. Voltmeters		8		TE		
	-5. Tube Tester		3		TE		
	-6. Technical Orders		3	CI			
	-7. Use and Care of Handtools		2		TE		
	III-9. Class I Trainer Equipment Utilization and Status Reporting		4	CI			
	IV-5. Maintenance Management and Maintenance Inspection System		10	CI			
	-7. Air Force Supply System		2	CI			
	-8. Flight Publications		2	CI			
	VII-1. Number System and Mathematical Operations		18	CI			
	-2. Boolean Algebra		20	CI			
	-3. Integrated Circuit Parameters and Packages		4	CI			
	IX-3. Programming/Diagnostics		23			SDS	
	-4. Flow Charts		2	CI			
			115 TOTAL				

Table B-2 (Continued)

C. General Conceptual Skills	VI-1. Navigation Theory, Problem Solving, and Operational Checks		12			SDS	
	-2. Navigation Systems		6			SDS	
	-3. Weapons Delivery Theory and Simulation		11			SDS	
	-4. Electronic Countermeasures Theory and Simulation		4			SDS	
	-5. Principles of Terrain Following/Terrain Avoidance Radar		3			SDS	
	-6. Console Operation		2			SDS	
			38 TOTAL				
D. System-Specific Knowledge	II-1. Power Generation Equipment	2	10				TT
	-2. AC and DC Distribution	2	12				TT
	III-1. AC Amplifiers	1,4	2				TT
	-2. DC Operational Amplifiers	4	2				TT
	-3. Multiplication Circuits	1,4	4				TT
	-4. Summing Circuits	4	17				TT
	-5. Integration Circuits	4	1				TT
	-6. Curve Duplication Circuits	4	10				TT
	-7. Vector Circuits	4,6,7	2				TT
	-8. Servo Systems	6,7,8,10	4				TT
	IV-1. Gray Code and Light Optic System	1,6,7	40				TT
	-3. Tri-color and Light Optics System	6,7	26				TT
	-6. Simulator Configuration	ALL	8				TT
	V-1. Theory and Operation of Visual Systems	6,7,10	10				TT
	-2. Theory and Operation of Closed Circuit Television Systems	3,6,7,10	14				TT
	-3. Television and Visual Circuit Analysis	3,6,7,10	7				TT
	VIII-1. Discrete Logic Elements	1,4	8				TT
	-2. Meory and Timing Elements	1,4	22				TT
	-4. Integrated Circuits and Functional Units	1,4	36				TT

Table B-2 (Continued)

	IX-1. Memory Systems	1	5				TT
	-2. CPU Control and Timing	1	8				TT
	X-1. Cyclic Computer Configuration	1	8				TT
	-2. Central Processing Unit and Programming	1	24				TT
	-3. On-line Utility Diagnostics	1	6				TT
	XI-1. Peripheral Equipment	1,5	16				TT
	-2. Interface/Linkage Systems	4	8				TT
	XII-1. Target Generation	4	10				TT
	-2. Digital Radar Landmass	6,7	4				TT
	-3. Computer Generated Imagery	6,7	9				TT
			333 TOTAL				
E. System-Specific Troubleshooting Activities	II-3. AC and DC Power, Operational Checks and Adjustments	1,2,4	6				TT
	IV-4. Maintenance Procedures	ALL	28				TT
	V-4. Operational Checks and Alignments	ALL	4.5				TT
	VIII-5. Troubleshooting Techniques	ALL	8				TT
	XI-3. Troubleshooting	ALL	9				TT
			55.5 TOTAL				

APPENDIX C

RESEARCH NEEDS

Research Needs

While simulation technology has been widely used for pilot training, the application of simulation technology for support of maintenance training is still in its infancy. Research and study efforts are needed to examine in detail the types of behaviors required for maintenance tasks and the types of simulation training needed to support maintenance skills. Some research issues developing from the effort described herein include the following:

1. General problem solving abilities should be studied as functions of solving many related troubleshooting problems. How much and how well will maintenance training on one specific system facilitate learning maintenance of another system?

2. Symbolic troubleshooting training versus hands-on training needs to be compared and evaluated as methods for training troubleshooting skills.

3. The *Troubleshooting* Trainer uses a concept of system analysis in terms of a "functional flow" and a "logic tree" method of information presentation. Can the symbolic and conceptual methods of the Troubleshooting Trainer, versus conventional methods, achieve for trainees a more thorough level of system understanding, and a higher level of maintenance skills?

4. The problem of adding instructional control to maintenance simulation needs to be studied with respect to learning and transfer of training. That is, how much of a teaching machine should a maintenance simulator be for maximum training effectiveness?

5. Fidelity of simulation in the realm of maintenance simulation needs to be examined in terms of supporting training and transfer of training. Fidelity of simulation needs to be examined with respect to categories of behavior, especially problem solving ability.

Trainer Development Effort

Of the three maintenance simulator concepts developed in this effort, two were selected for translation into prime item specifications. One trainer concept is a low cost generalized applied-skill trainer called a "scaled-down simulator." The second trainer is a low cost conceptual trainer for supporting system-specific troubleshooting skills. These two training devices complement each other, the former providing "hands-on" training for basic supporting skills during the early stages of training, and the latter providing training on specific flight simulator systems appropriate for the later stages of learning, and for on-the-job training.

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